In-vitro mechanically-assisted corrosion of modular stainless steel - CoCr junctions: Comparisons of materials, initial moisture and offset length

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INTRODUCTION

It was recently shown that 316L SS modular intramedullary rods retrieved from patients demonstrated severe corrosion attack in the modular taper[1]. A direct consequence of this corrosion was the development of osteolysis immediately surrounding the taper junction as well as cortical wall thickening in several cases. These results continue to point to the corrosion-related concerns of modularity in many different designs, devices and applications. The products from these corrosion reaction can impact both local and distant sites in the body and raise levels of ions in the blood and urine.

An increasing number of biomedical alloys are being considered for use in modular implants. One such alloy is REX 734 (Orthinox 90TM, ASTM F1586), a stainless steel alloy currently in use in the stem-component of total hip replacements (in Europe). While fretting-crevice corrosion has been shown to occur in femoral hip tapers not made from stainless steel, and that stainless steel modular IM rods have been shown to be susceptible to this form of degradation, it is important to assess the susceptibility of stainless steel-based hip stems to corrosion at the taper junction when used with a CoCr head alloy under fretting crevice corrosion conditions. Furthermore, head offset and taper assembly (either wet or dry) may have effects on modular taper corrosion behavior and need to be assessed.

The goals of this study were: 1) to assess and compare a femoral hip stem design consisting a stainless steel stem and CoCr head to fretting crevice corrosion; 2) to assess the effects of moisture initially present within the taper crevice compared to an initially dry assembly; 3) to assess if head offset affects the mechanical environment and the fretting corrosion process.

MATERIALS AND METHODS

Four different sample groups were tested. These were: 1) CoCr/SS, 0mm offset, wet assembled (SSwet), 2) CoCr/CoCr, 0 mm offset, wet assembled (CoCr), 3) CoCr/SS 0mm offset, dry assembled (SSdry), 4) CoCr/SS, 6 mm offset wet assembled (SS6mm). The fretting corrosion test setup measuring voltage (V) and currents (I), is outlined in the schematic Fig 1. Samples were tested according to a protocol laid out in Fig. 2. Additionally, direct assessment of the micromotion between the head and neck components were made using a linear variable differential transformer (LVDT, Schaevitz Engineering). Motion was measured in both 0 mm SS/CoCr and 6mm SS/CoCr couples over a range of cyclic loads similar to the short term tests described above. Microscopic analysis of the taper surfaces after fretting corrosion testing was performed with scanning electron microscopy and optical microscopy as a means of relating observations of surface damage with the measured corrosion rates. Micromotion results were analyzed for magnitude and direction of LVDT motion as a function of applied cyclic load.

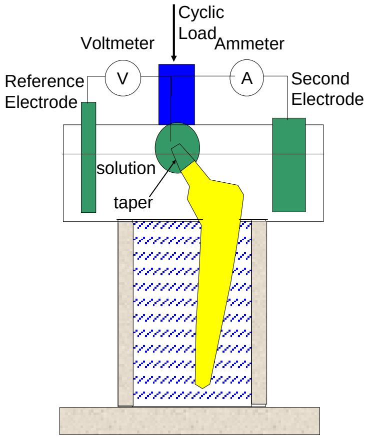


Fig. 1: Schematic of the test assembly used for performing the fretting-corrosion tests.

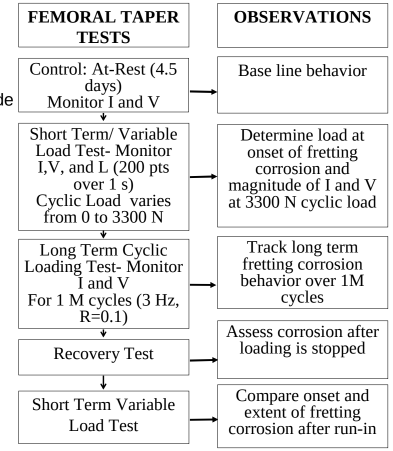


Fig. 2: Flow chart of testing protocol. Each sample was subjected to each of these tests.

RESULTS

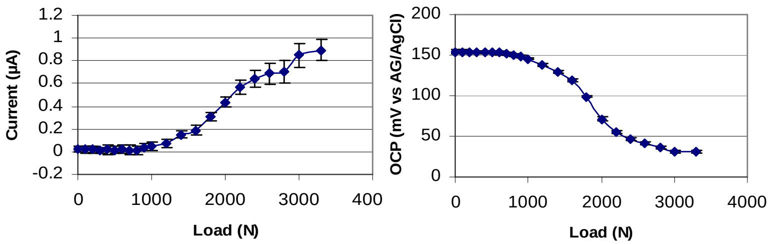
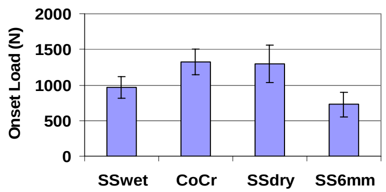


Fig. 3: Typical results of short-term test. OCP and current versus applied cyclic load magnitude (CoCr6). Note the change observed in both current and voltage at about 1000 N applied cyclic load. This represents the onset load for fretting corrosion.

Fig. 4:Summary of onset loads for the four groups tested in the first short-term test →



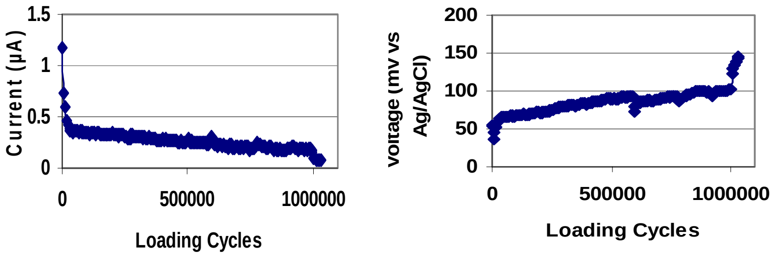


Fig. 5: Typical results from a long-term test. Note the current and voltage return close to control conditions during the progression of long-term test (run in period).

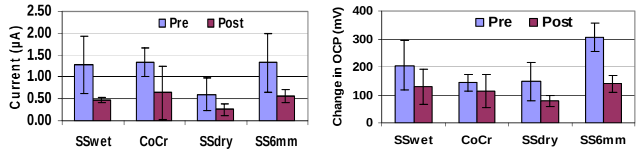


Fig. 6: Left: Change in OCP ; Right: increase in current, from short term tests for both the pre- and post-1M cycle loading. Note: OCP drops with loading but is shown here as positive. OCP and current do not change as much after 1 M cycles of loading.

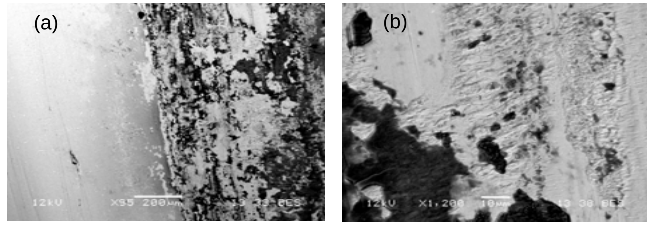
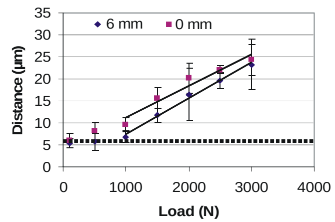


Fig. 7: Backscattered electron images of a 6 mm Stainless Steel neck taper (SS17) after testing. a) low magnification, b) higher magnitude backscattered electron images. The dark debris in the lower left of (b) is corrosion product, while the scars in the center and right of the image are indicative of fretting corrosion attack.

Fig. 8: Summary of micromotion amplitude versus applied cyclic load. Distances are peak-to-peak (n=3 for each type). It appears that 0 mm heads piston while 6 mm heads rock on the trunion.



DISCUSSION

In summary, the results showed that 1) SS/CoCr couples were more susceptible to fretting corrosion than CoCr/CoCr couples, 2) that dry assembly does not prevent fretting corrosion from taking place (but raises the onset loads) and 3) that 6 mm offset heads initiated fretting at lower onset loads. Visual evidence showed more corrosion in 6 mm heads than 0 mm heads, however, electrochemical measurements did not show clear differences in fretting corrosion. The voltage shifts were larger for 6 mm offsets, but the currents were not significantly different. Micromotion measurements indicated fretting motions in the range of 10 to 25 µm where 0 mm heads tended to piston on the trunion, while 6 mm heads tended to rock.

Glossary

Fretting Corrosion: A special wear process that occurs at the contact area between two materials under load and subject to minute relative motion by vibration or some other force.

Literature

[1] Jones, D, et al. "Focal Osteolysis at the Junctions of a Modular Stainless Steel Femoral Intramedulary Nail", J. Bone and Joint Surgery, Vol. 83-A, No. 4, pp 537-548, April 2001.

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